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HIGH ALTITUDE ATOMIC NITROGEN DENSITIES.(U)
SEP 77 E S ORAN, D F STROBEL, K MAUERSBERGER

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High Altitude Atomic Nitrogen Densities

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Theoretical calculations of the seasonal and diurnal variations of atomic nitrogen are compared to measurements made by the open source neutral mass spectrometer on the AE-C satellite. Using as input the simultaneous measurements of molecular nitrogen and atomic oxygen densities, the calculations of odd nitrogen densities made with the NRL ionosphere model predict the same trends in atomic nitrogen as those observed. Estimates are given of the sensitivity of atomic nitrogen densities to variations in the photoelectron flux, the neutral temperatures, and the neutral winds. We find

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20. Abstract (Continued)

that within the range of uncertainties in these quantities, the magnitude of the calculated and observed atomic nitrogen densities are in good agreement.

CONTENTS

HIGH ALTITUDE ATOMIC NITROGEN DENSITIES

I. Introduction

The recent measurements by Mauersberger et al. (1975, 1976 a and b) with the open source neutral mass spectrometer (OSS) on the Atmosphere Explorer-C satellite provide direct observations of atomic nitrogen densities from about 350 to 600 km. Previously atomic nitrogen densities were inferred from $N(^2D)$ and NO emissions measured in the middle thermosphere. For example, optical spectroscopy techniques have been used on rockets to detect chemiluminescence and fluorescence emissions from NO (Feldman and Takacs, 1974; Gerard, 1975). Although extraction of atomic nitrogen densities from this data is difficult because the densities of O_2 and O were not measured simultaneously, theoretical analyses were able to put reasonable limits on these quantities (Strobel et al., 1976). Analyses of AE-C measurements of $N(^2D)$ 5200Å and NO $\gamma(1,0)$ band emissions, coupled with neutral and ion density and temperature data, yielded $N(^4S)$ densities (Rusch et al., 1975; Frederick and Rusch, 1977, Strobel et al., 1976; Torr et al., 1976).

The purpose of this paper is to compare the measurements of atomic nitrogen densities made by the OSS instrument with theoretical model calculations. In addition to [N], the mass spectrometer measurements provide most of the input quantities for our theoretical model and we can limit the number of adjustable parameters. The densities of molecular oxygen were not measured and they must be inferred from other measurements at lower altitudes. The other unknown parameter is the

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production rate of atomic nitrogen by photoelectron impact on N_2. Uncertainties are associated with both the magnitude of the absolute cross sections for electron impact dissociation of N_2 at low energies, $\sim$ 10-30 ev, (E. Zipf, private communication, 1976) and the magnitude of the photoelectron flux above 250 km. The other important production rate of [N], Lyman-ν photon absorption by N_2 at 972.5Å, is subject to considerably less uncertainty than electron impact dissociation (Oran et al. 1974).

From the work presented below, we conclude that there is good agreement between the measured atomic nitrogen densities at high altitudes and those predicted by our model calculations. The major uncertainty in daytime densities is the calculated magnitude of the high altitude photoelectron flux. The observed and calculated densities are consistent to within the flux uncertainty. The calculated diurnal variation may be to a factor of two larger than observed. A major part of this discrepancy can be removed by the inclusion in the model of the effects of horizontal transport of atomic nitrogen by thermospheric winds.

II. Data

The open source neutral mass spectrometer on AE-C provided the first extensive coverage of atomic nitrogen densities in the upper thermosphere. The procedure for data analysis has been discussed by Mauersberger et al. (1975). Within the ion source of the mass spectrometer, most of the nitrogen atoms combine with atomic oxygen to form NO. The measured densities of NO can be used to quantitatively derive atomic nitrogen densities. A pronounced diurnal as well as seasonal variation has been observed.

In order to compare model predictions with experimental results, three sets of data from geomagnetically quiet conditions were selected. Each set contains densities of N, N_2, and O measured by OSS. Most of the data were previously discussed by Mauersberger et al. (1976 a and b). Figures 1 and 2 summarize the experimental results.

Figure 1 consists of compilations of two sets of ten orbits, one set representing winter (early February, 1974) and the other summer (late June, 1974) conditions in the northern hemisphere. Figure 2 shows the diurnal variation of [N]: the ascending (2 LT) and descending (17 LT) legs of the orbit in April 14, 1974, during equinox. Relevant parameters for the data sets are summarized in Table I. Exospheric temperatures are derived from the N_2 scale heights. The absolute accuracies of N_2 and O densities are ± 10%, while the N densities above 10^5 particles/cm^3 are estimated to be within ± 25%. Lower densities have a larger statistical error due to low count rates.

III. Model

The theoretical analysis was performed with the NRL one-dimensional model of the mid-latitude ionosphere (Oran et al., 1974). This model describes the time and altitude dependent structure of the odd nitrogen constituents as well as the ion and electron densities and temperatures from 70 to 1000 km. Previous odd nitrogen studies using the same model were published by Oran et al. (1975) and Strobel et al. (1976). For the high altitude nitrogen studies presented here, we have adopted the currently accepted chemical rate constants determined by extensive analysis of AE data (Torr et al., 1977). The calculations presented below use the OSS density measurements of N_2 and O which were obtained together with the atomic nitrogen density.

To determine appropriate molecular oxygen densities, we assume that this specie is in diffusive equilibrium above 200 km (Oran and Strobel, 1977). Then we can use the OSS measurements by Nier et al. (1976) and Kayser and Potter (1976) on AE-C and -D as a guide for selecting appropriate densities at the locations and seasons of interest. For winter at high latitudes, they show that $[O_2]$ at 200 km can range from $1.5 - 3.0 \times 10^8$ cm^{-3}. The mid-latitude region from 40 °N to 40 °S has a fairly constant $[O_2]$ at 200 km of 1.7×10^8 cm^{-3}. The daytime maximum values used in the calculation are given in Table I.

The major uncertainty in the atomic nitrogen densities is associated with its production by electron impact dissociation of N_2. We attempt to bound this quantity by first considering the limits and reliability of the theoretically calculated electron fluxes and then estimating the effect of new measurements of the absolute dissociation cross section.

The NRL photoelectron transport model (Oran and Strickland, 1976) was used to generate the required electron fluxes and includes the effects of energy degradation, production, scattering, and transport processes with sufficient aeronomic detail. As illustrated in Figure 3, agreement between measured and calculated fluxes below 60 ev and 200 km is excellent. The data shown for energies over 60 ev represent the minimum count rate of the photoelectron spectrometer and overestimate the actual flux. At high altitudes the magnitude and anisotropy of the photoelectron flux are controlled by transport processes. Two transport effects not presently included in our calculation are magnetic mirroring and the additional influx of particles from the conjugate hemisphere. Analysis of AE data (Peterson et al. 1977) as well as numerous indirect electron flux observations from incoherent radar backscatter and airglow measurements indicate the importance of the influx of conjugate point electrons to the total flux. When this effect occurs, i.e. during times when the sun is down and the conjugate point is lit or when there is differential heating between the northern and southern hemisphere, escaping electrons travel along the magnetic field lines and provide a substantial contribution to electron fluxes. Recent calculations of the [illegible] of the steady state population of photoelectrons in the plasmasphere which include magnetic trapping of electrons indicate that our calculated values may be too low by 25-50% (Mantas et al., 1977) during times when these effects are important.

Another uncertainty in our electron flux calculation is in the degree of anisotropy considered for elastic collisions between electrons and O, N_2 and O_2. Figure 4 shows the results of two calculations which compare photoelectron fluxes at 400 km for both forward peaked and isotropic elastic scattering. Comparison of the elastic cross sections for atomic oxygen which we have used and those calculated by Blaha and Davis (1975) indicate that our resulting flux anisotropy may be too large. However we lack comparable data for N_2 and O_2. Thus we consider the set of curves in Figures 4 as bounding the anisotropy arising from elastic collisions. From Figure 5 we find that the net effect of isotropic elastic collisions would be to increase the magnitude of the flux in the 300-600 km range by as much as a factor of two for energies above 20 ev and decrease them by at most 50% for energies less than 20 ev.

The major contribution to N_2 dissociation channels is from photoelectrons with energies greater than 20 ev. Further detailed analyses of anisotropic effects will be published elsewhere. However, our conclusion from this analysis as well as preliminary comparisons with AE data (Peterson, private communication) is that our calculated electron fluxes above 20 ev in the 300-600 km altitude regime may be too low, but at most by an overall factor of two.

The electron impact cross sections for N_2 dissociation measured by Winters (1966) include not only pure dissociation channels but an undetermined percentage of the dissociative ionization channel. A detailed discussion of the excited states which contribute to dissociation is given in Oran et al. (1975). A recent experimental effort to obtain better resolution of the cross sections and product states indicates that Winters' values may be too small below about 30 ev (Ed Zipf, private communication). While we have used Winters' values in our calculations, we also evaluate the effect of larger N_2 dissociation rates.

Figure 6 shows a typical N_2 dissociation rate calculated using the photoelectron fluxes obtained assuming anisotropic collisions and the Winters' cross sections. Enhancing the cross sections by a factor of three at 15 ev and scaling the lower energy values appropriately gives an overall 25-30% increase in the production rate of atomic nitrogen.

IV. Results and Discussion

Figures 7 and 8 summarize typical results of our calculations. We have used the electron fluxes which allow for anisotropic elastic scattering. The seasonal comparison in Figure 7 shows calculated and measured atomic nitrogen densities for data which are compilations of measurements made between 8 and 10 LT. For these high altitude summer measurements, the sun never sets. The winter discrepancy between the calculated and measured 8 LT densities and the data can be reduced substantially by including in our nighttime calculation the effects of conjugate point electrons.

Calculations of the diurnal variation of atomic nitrogen are compared to with equinoctal data in Figure 8. Good agreement is shown for the daytime densities (17 LT), however model calculations are about a factor of three lower than the nighttime data at 2 LT. Contour plots of atomic nitrogen densities, shown for this April calculation in Figure 9, indicate a diurnal variation at 400 km of a factor of 15. The minimum and maximum values occur at 5 and 15 LT respectively.

The density of atomic nitrogen at the high altitudes considered here is extremely sensitive to the photoelectron flux. Using the calculations in Figures 7 and 8 as a base, we found that increasing the high altitude electron flux by a factor of two increases the daytime atomic nitrogen densities by 50%. Figure 10 shows the winter calculation of atomic nitrogen densities at 10 LT with the flux above 250 km enhanced by factors of 2 and 3. (In these calculations we have let the increase go from zero to 2 or 3 linearly in the region between 200 and 250 km). At 400 km the dominant production rates of atomic nitrogen are photoelectron impact on N_2 and pre-dissociation of N_2 through photoabsorption in the 800-1000Å range. These two production rates are roughly comparable at high altitudes and they are about an order of magnitude more important than $O^+ + N_2 \rightarrow NO^+ + N(^4S)$ which is of comparable importance at 200 km.

Atomic nitrogen densities are partially controlled by the reaction $N + O_2 \rightarrow NO + O$ at lower altitudes. Higher $[O_2]$ depletes N at low altitudes and increases the downward transport rate until the high altitude [N] is reduced by a comparable amount. We have found that decreasing $[O_2]$ by a factor of two increases [N] by $\sim$ 50%. On the basis of the Nier et al. (1976) and Kayser and Potter (1976) observations, these O_2 densities would be unrealistically low.

The difference between calculated and observed nighttime [N] can be reduced if we include the effects of thermospheric winds which transport N atoms from the day side to the night side of the globe. For typical horizontal winds $\sim$ 150-200m/sec, we estimate that the effect of the east-west winds is to reduce the diurnal variation by $\sim$ 30% and to significantly reduce the [N] decay rate at night from that shown in Figure 9.

V. Conclusion

Understanding the high altitude densities of atomic nitrogen depends primarily on understanding the effects of a number of transport processes. First, we need to know the high altitude photoelectron flux to better accuracy, which requires a correct description of the magnetic mirroring and conjugate point effects as well as better data on the anisotropy of elastic cross sections. The magnitude of the electron flux is the largest uncertainty in our calculation of daytime [N]. In addition, the magnitude of the low energy electron impact cross sections for N_2 dissociation is questionable. In our calculations we may have underestimated both the flux and the cross sections.

The other transport process, which is crucial to determining nighttime [N], is horizontal transport from the day side. Quantitative resolution of the importance of this effect requires a multi-dimensional model of neutral winds, densities, and temperatures.

A final point we wish to make is that we are comparing a one-dimensional calculation with a three-dimensional satellite observation. The April data scans a 14° range in latitude whereas the calculations were done at an intermediate latitude. Local fluctuations or longitude dependent phenomena occurring in the data will not be reproduced by our models. Of particular importance are thermospheric temperatures. The atomic nitrogen densities at 400 km are approximately four scale heights above the altitude where densities are determined by chemical processes. Small errors in the assumed temperatures in our model can lead to large errors in [N] and its high altitude diurnal variation.

In conclusion, we feel that given the uncertainties in the transport effects mentioned above, we can account for the high altitude atomic nitrogen density observations.

Acknowledgements

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Table I

Season	Dates	Latitudes	~ Local Times	T_∞	$[O_2]$ 200 km (estimated)
Winter	Feb. 6-9 1974	~ 67 °N	8-10 LT	800 °K	$2x10^8$ cm^{-3}
Summer	June 21-27, 1974	~ 67 °N	8-10 LT	950 °K	$2x10^8$
Equinox (April)	April 14, 1974	~ 40-50 °K	17 LT 2 LT	950 °K 720 °K	$1.5x10^8$

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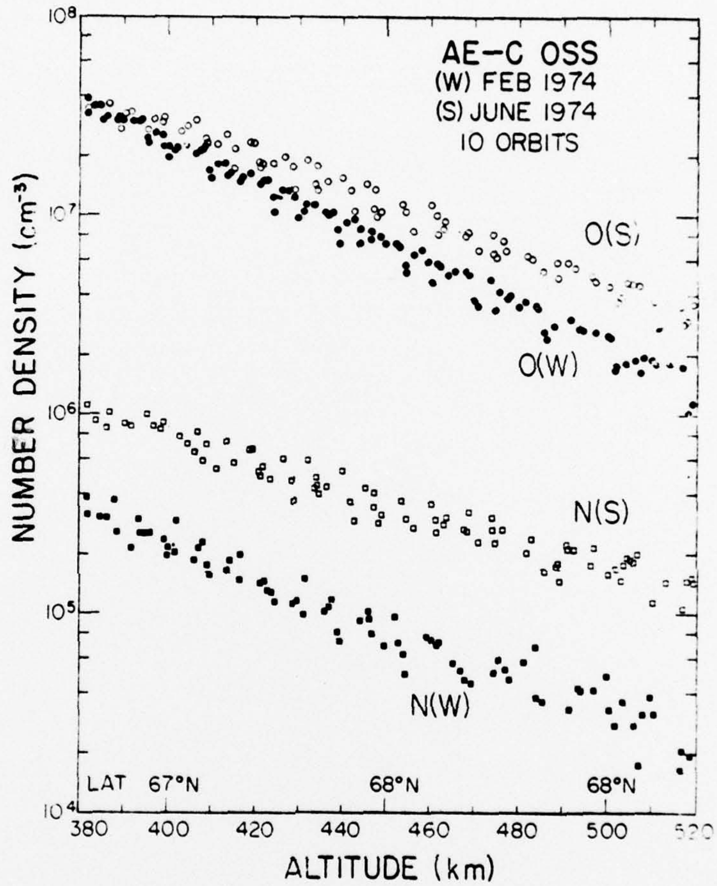

Fig. 1 — Atomic nitrogen and oxygen densities measured by the open source neutral mass spectrometer (OSS) for summer (S) and winter (W) orbits.

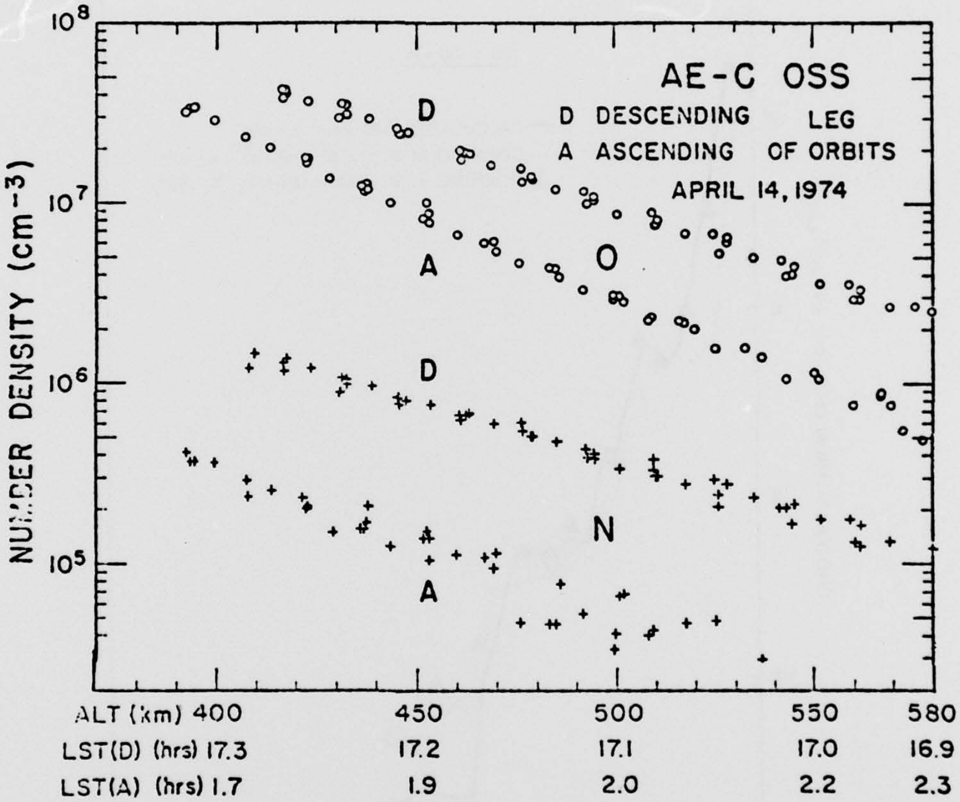

Fig. 2 — Comparison between daytime and nighttime atomic nitrogen and oxygen densities at equinox.

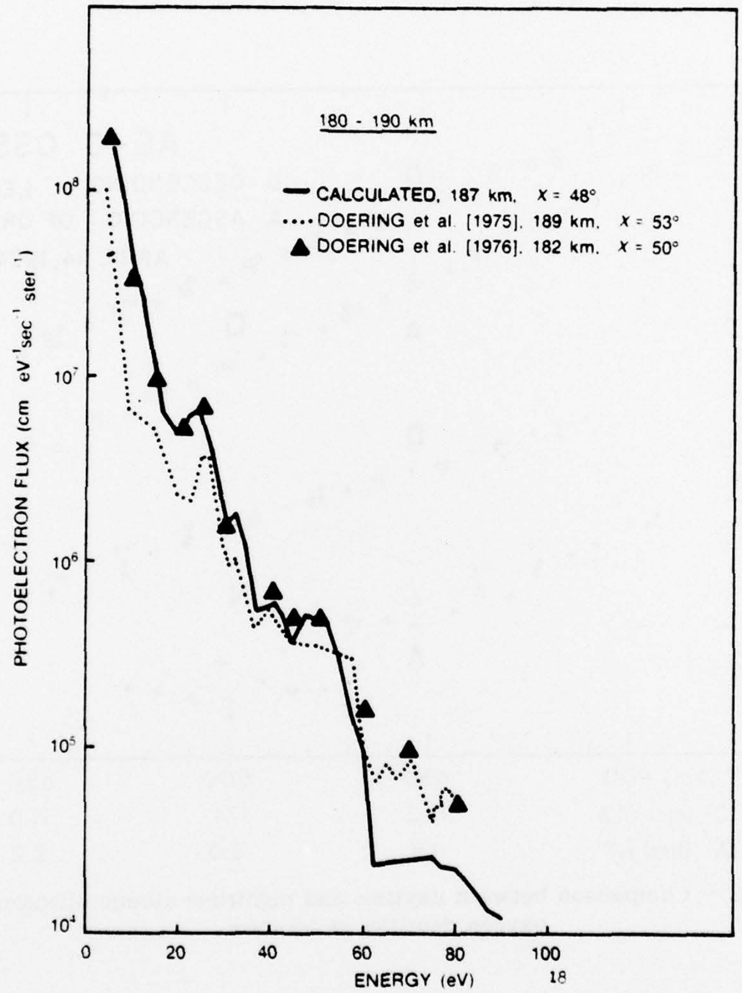

Fig. 3 — Comparison of calculated photoelectron fluxes at 187 km with satellite observations at 189 and 182 km.

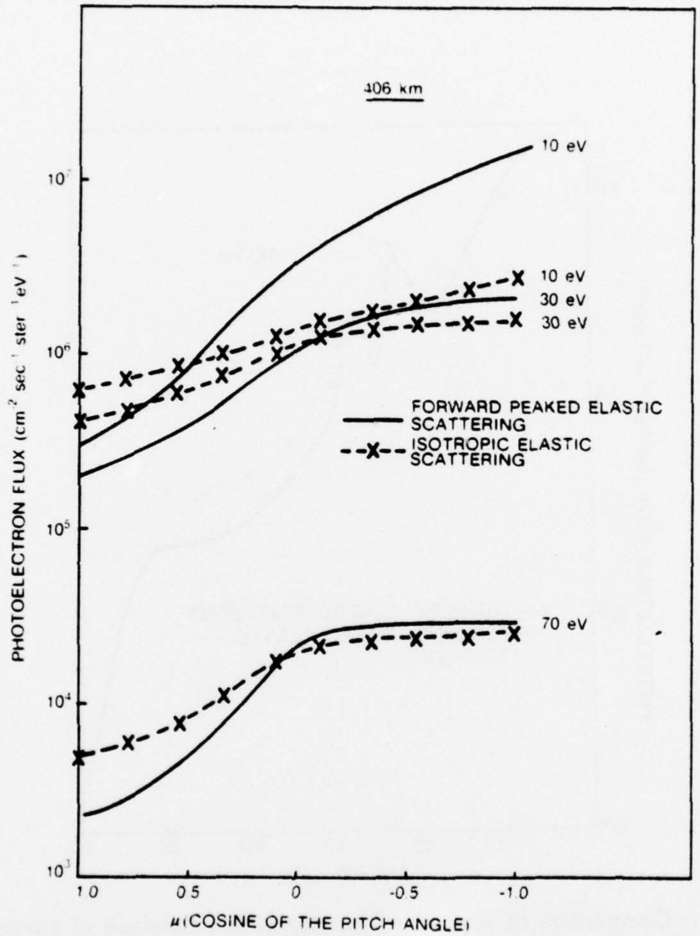

Fig. 4 — Photoelectron flux as a function of μ, the cosine of the pitch angle, for isotropic and forward peaked elastic scattering. The value $\mu = 1$ ($\mu = -1$) corresponds to down (up) the magnetic field line.

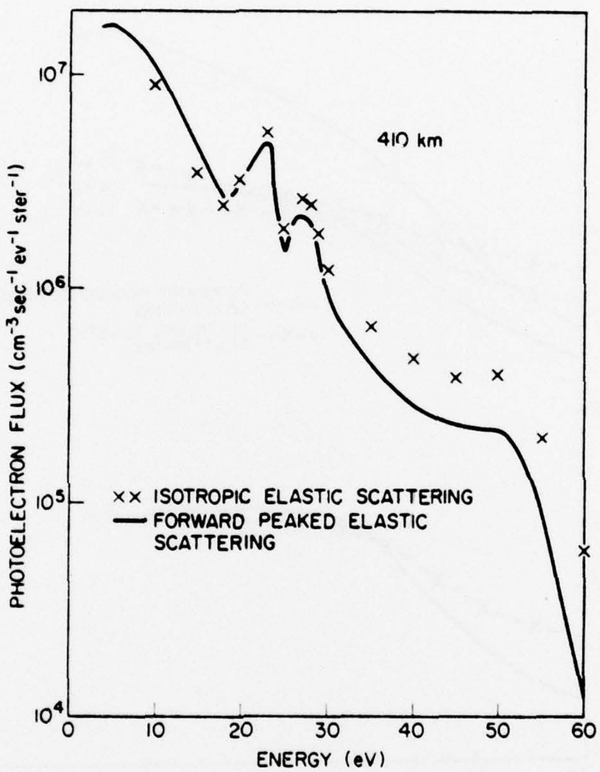

Fig. 5 — Comparison of photoelectron fluxes as a function of energy at 410 km for isotropic and forward peaked elastic scattering.

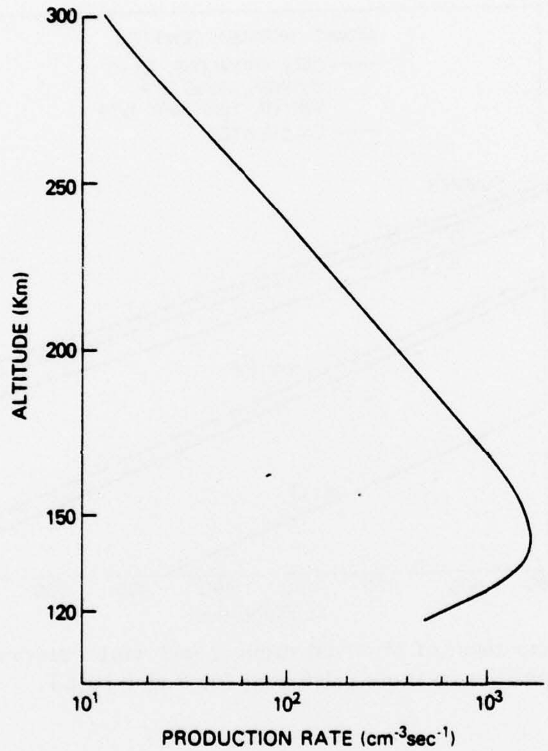

Fig. 6 — Production rate of atomic nitrogen by electron impact on N_2, calculated for a zenith angle, $\chi \equiv 60°$, exospheric temperature, T_∞ 880° K.

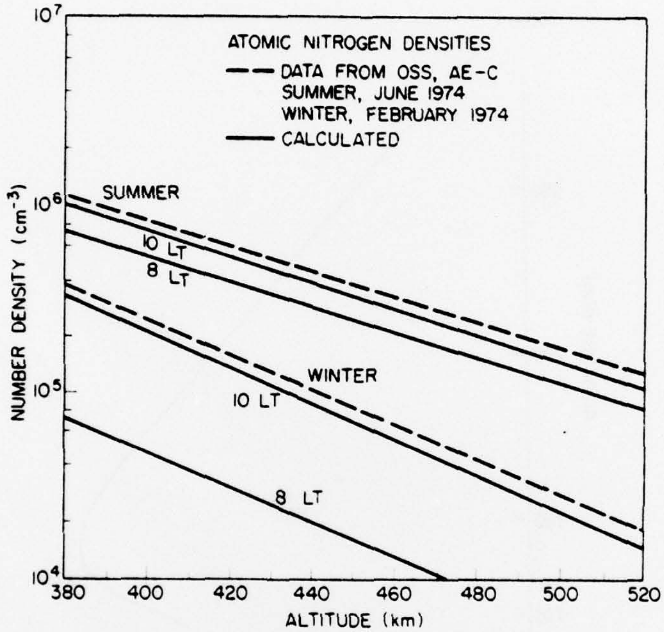

Fig. 7 — Comparison of observed summer and winter atomic nitrogen densities to those calculated for 8 and 10 LT.

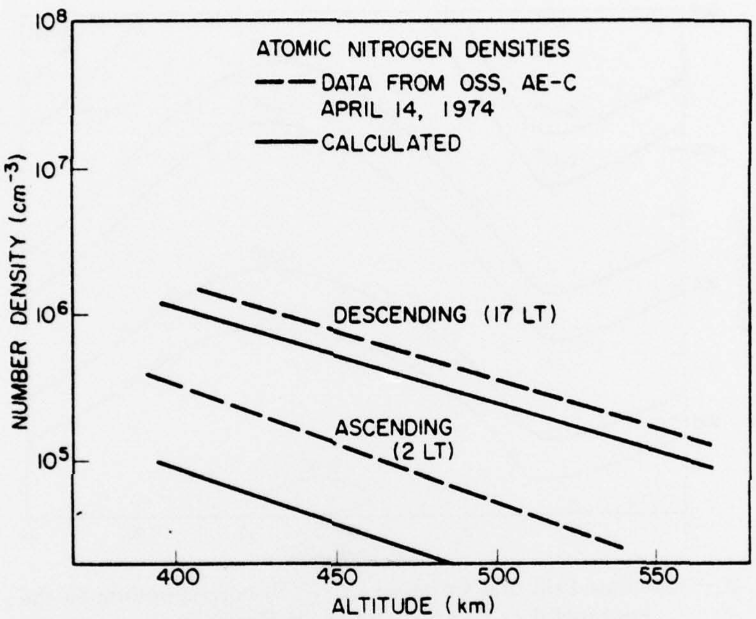

Fig. 8 — Comparison of observed and calculated atomic nitrogen density profiles for equinoctal conditions at 2 and 17 LT.

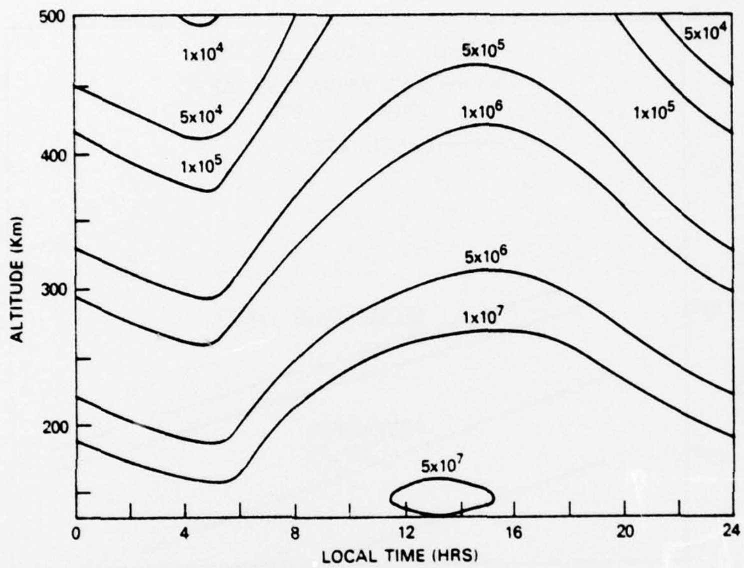

Fig. 9 — Calculated diurnal variation of N(^{4}S) corresponding to the equinoctal calculation shown in Figure 8.

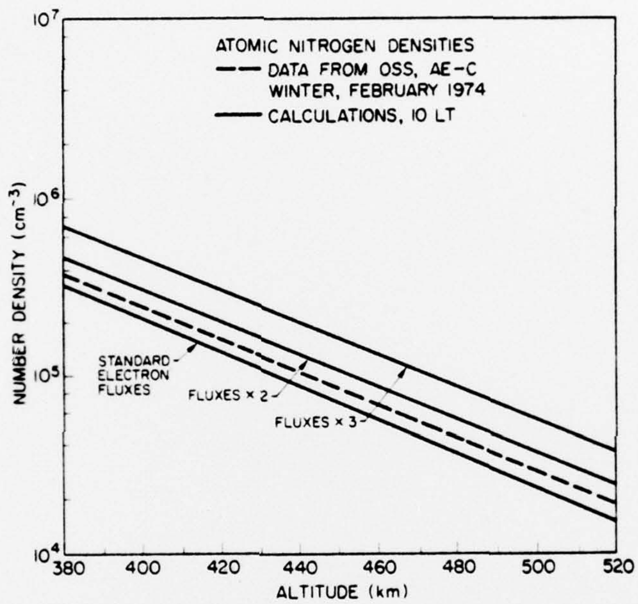

Fig. 10 — Calculations of altitude profile of atomic nitrogen densities which show the effect of increasing the high altitude photoelectron fluxes.